Department of Energy
Washington, DC 20585

Safety Evaluation Report
for the
ATR Fresh Fuel Shipping Container

Docket No. 97-08-9099

SUMMARY

Based on the statements and representations in the Safety Analysis Report for Packaging (SARP), the staff has concluded that the ATR (Advanced Test Reactor) Fresh Fuel Shipping Container design meets the requirements of DOE Order 460.1A, 10 CFR Part 71, and 49 CFR Part 173. There are 21 containers (No. 4 through 24) that meet these requirements. There is no intention to build new containers.

REFERENCE

ATR Fresh Fuel Shipping Container Safety Analysis Report for Packaging, INEL-94/0275, (Formerly EGG-PRP-10587), Rev. 4, September 13, 1997, Idaho National Engineering and Environmental Laboratory (INEEL), Lockheed Idaho Technologies Company, Idaho Falls, ID.

DRAWINGS

The ATR Fresh Fuel Shipping Container is defined by the following EG&G Idaho, Inc. drawings:

Title	Drawing No.	Sheet Nos.	Rev. No.
ATR Fresh Fuel (Inner) Shipping Container	445721	1-3	none
ATR Fresh Fuel (Outer) Shipping Container	445722	1-2	A
ATR Fuel Element Shipping Box Protective Container Assembly and Detail	438911	1 2 3-5	F F Original

CHAPTER 1 - GENERAL

The general information and drawings presented in the reference were reviewed by the staff and found acceptable. The ATR Fresh Fuel Shipping Container is adequately described by the above assembly and attendant drawings which provide specifications for the materials of construction, component dimensions, location, size, and type of weld joints on the packaging. The SARP states that there is no intent to fabricate new packages using the detailed design drawings. For this reason acceptance testing, procurement, and fabrication requirements for new packages are not included in the SARP. Tamper-indicating seals are installed on the container.

The ATR Fresh Fuel Shipping Container is a Type B, Fissile Material container for shipping fresh (unirradiated) fuel elements for the Advanced Test Reactor (ATR) and is also a Category III container as defined in NRC Regulatory Guide 7.11.

Section 1.2.1 of the ATR Fresh Fuel Shipping Container SARP calls out visual examination of the welds in the containers according to the rules of Section III, Subsection NG of the ASME Boiler and Pressure Vessel Code. This is the appropriate code subsection for structures that hold fissile materials in place during shipment. Other ASME Code rules generally applicable to radioactive material packaging containments do not apply to the ATR because the containment requirements are satisfied by the ATR contents, that is the fuel plates themselves, rather than by the packaging. Staff review of the fuel plate fabrication procedures indicates that the containment integrity achieved by the fuel plates themselves is comparable to that achieved in vessels constructed to the ASME Section III rules. The ATR SARP does not address ASME Section III requirements since the function of the packaging is confinement of the contents and mitigation of hypothetical accident effects rather than containment.

The total gross weight of the fully loaded container is 387 kg (853 lb). The container is shipped as an exclusive use package. The results of the confirmatory analysis provided in Section 4.1.2 of this SER indicate that this packaging must be shipped as exclusive use to satisfy the requirements of 10 CFR 71.87(i). Therefore the Certificate of Compliance as a condition restricts the ATR package to exclusive use shipments.

This SER directly evaluates and assesses the integrity of the components that comprise the containment boundary and evaluates the ability of the outer protective containers to provide protection to the fuel elements, which comprise the containment boundary, during the Normal Conditions of Transport and Hypothetical Accident Conditions defined by DOE Order 460.1A and 10 CFR Part 71.

1.1 Description

1.1.1 Packaging

The packaging consists of an outer container, an inner container, and the fuel elements. The containment boundary of the ATR Fresh Fuel Shipping container consists of the outer fuel plate cladding and the uranium-aluminum fuel core. The outer container serves as a protective container for the inner container and fuel elements.

Outer Container The outer container is a rectangular parallelepiped made with an upper half (lid) and a bottom half. The lid is connected to the bottom by four 10.2-cm by 0.30-cm (4-inch by 0.120-inch) thick broad butt hinges (two on each long side) with removable and lockable pins. The lid and bottom are made from 18-gauge ASTM A 366 carbon steel sheet covering 2.54-cm (1-inch) thick fir plywood. The hinges are made from ASTM A 366 carbon steel, and are welded to the sheet metal on the lid and bottom.

Both the lid and bottom have a structural angle framework around the exterior edges. The structural angles are made from 2.9 x 2.9 x 0.3 cm and 5.1 x 5.1 x 0.3 cm (1 1/8 x 1 1/8 x 1/8 inch and 2 x 2 x 1/8 inch) ASTM A 36 steel. There are three oak skids bolted to the bottom half of the container with three 1.0 cm diameter (3/8-inch) ASTM A 307 carriage bolts per skid.

The outer container has two 14.0-cm (5 1/2-inch) thick shock absorbers, one at each end of the container. These shock absorbers consist of an outer plate made from 1.3-cm (1/2-inch) thick fir plywood, a 10.2-cm (4-inch) thick honeycomb block made from ASTM B 209(5052), 0.006-cm (0.0025-inch) sheet aluminum with a unit weight of 0.11 gm/cm^3 (6.9 lb/ft^3) and a crush strength of 3.96 MPa (575 lb/in^2), and an inner plate made from two pieces of 2.5-cm (1-inch) thick fir plywood. This assembly is sheathed on three sides and the face with 18-gauge ASTM A 366 carbon steel sheet. The four corners are reinforced by angles made from 16-gauge ASTM A 366 carbon steel sheet. These angles are welded to the steel sheet covering. The external dimensions of the shock absorbers are 80.6 cm (31 3/4 inches) wide, 28.4 cm (11 3/16 inches) high, and 14.0 cm (5 1/2 inches) thick. The shock absorbers are attached to the bottom half of the container by tack welds.

The external dimensions of the outer container, including shock absorbers, are 222.7 cm (87 11/16 inches) long, 80.6 cm (31 3/4 inches) wide, and 28.4 cm (11 3/16 inches) high. With the 7.0-cm (2 3/4-inch) high oak skids, the total height is 35.4 cm (13 15/16 inches). The weight of the outer container is 204 kg (450 lb).

Inner Container The inner container is a rectangular parallelepiped made with an upper half (lid) and a bottom half. The lid and bottom are made from 16-gauge carbon steel sheet covering 1.9-cm (3/4-inch) thick fir plywood. The lid is connected to the bottom with a full-length piano hinge on one long side and two 7.6-cm by 10.2-cm (3-inch by 4-inch) broad butt hinges on the opposite side. The butt hinges have removable and lockable pins. The piano hinge is attached by No. 5 (0.32 cm [0.125 inch] diameter) machine screws and wood screws. The butt hinges are made from carbon steel, and are welded to the steel sheet on the lid and bottom. The external dimensions of the inner container are 176.4 cm (69 7/16 inches) long, 68.1 cm (26 13/16 inches) wide, and 17.6 cm (6 15/16 inches) high.

The interior of the lid and bottom are lined with 1.3-cm (1/2-inch) thick high-density polyethylene sheet. The polyethylene is covered on the inside of the container by 0.05-cm (0.020-inch) thick cadmium sheet. The sides are also covered on the inside by 0.05-cm (0.020-inch) thick cadmium sheet.

The interior fuel element cavity is 171.4 cm (67.5 inches) long, 63.5 cm (25.0 inches) wide, and 10.2 cm (4.0 inches) high. The cavity contains trapezoidal spacers that divide the cavity into four fuel element compartments. These spacers are made from fir wood blocks lined with 1.0-cm (3/8-inch) thick sponge rubber made to ASTM D 1056-59T. The spacers are attached to the bottom of the inner container by 0.64-cm (1/4-inch) diameter carriage bolts that are welded to the outside sheet steel. Each trapezoidal fuel element compartment is approximately 132.1 cm (52 inches) long, 3.8 cm (1 1/2 inches) wide at the bottom, 10.5 cm (4 1/8 inches) wide at the top, and 10.2 cm (4 inches) high. A space of approximately 19.7 cm (7 3/4 inches) at each end of the cavity without the trapezoidal spacers is to accommodate the fuel element end boxes. The weight of the inner container is 143 kg (315 lb).

Containment Boundary The containment boundary consists of the outer surfaces of the fuel plate cladding and the uranium-aluminum fuel core. A metallurgical bond between the uranium-aluminum core and the cladding is formed by hot rolling. The fuel plate cladding is the exterior containment boundary for the radioactive contents, and is made from ASTM B 209 (6061-TO) aluminum sheet. The nineteen fuel plates are rectangular parallelepipeds rolled to approximately 45° annular segments and assembled into a fuel element assembly. The fuel element assembly and fuel plates are described by the Aerojet Nuclear Co. drawings 405400 Sheet 1 Rev. N, Sheet 2 Rev. N, and Sheet 3 Rev. G. The fuel plate thickness, fuel thickness, and minimum cladding thickness are given below.

Fuel Plate No.	Total Thickness, cm (in.)	Fuel Thickness, cm (in.)	Minimum Cladding Thickness, cm (in.)
1	0.20 (0.080)	0.05 (0.020)	0.08 (0.030)
2-18	0.13 (0.050)	0.05 (0.020)	0.04 (0.015)
19	0.25 (0.100)	0.05 (0.020)	0.10 (0.040)

1.1.2 Operational Features

The ATR Fuel Shipping Container is lifted by a forklift using the space between the oak skids for the lifting forks. There are no tie-down devices attached to the packaging; it is secured during transport by overwrapping straps or chains. The packaging has a nameplate attached to the outer container.

Weight Summary

Component	Weight, kg	Weight, lb
Outer Container	204	450
Inner Container	143	315
ATR Fuel Elements (four)	40	88
Total Weight	387	853

1.2 Contents

The ATR Fresh Fuel Shipping Container is designed to transport fresh (unirradiated) fuel elements from the supplier to the ATR at INEEL. Each container is designed to transport up to four fuel elements. According to the SARP, the limits on the contents of the ATR Fresh Fuel Shipping Container are four fuel elements, each containing a maximum of 1,100 g of U-235 with a maximum enrichment of 93 wt.%. The fuel elements will be sealed in a polyethylene bag prior to shipment. Upon the Applicant's request, the confirmatory analysis documented in this Safety Evaluation Report was performed for a maximum enrichment of 94 wt.% to allow for fuel elements with enrichments within manufacturing tolerances but slightly above 93 wt.% enrichment.

The ATR fuel plates consist of a uranium-aluminum core surrounded by an aluminum cladding that serves as the exterior containment boundary. The fuel core is fabricated by powder metallurgy using 100-mesh maximum size spherical aluminum powder made to Military Specification MIL-A-81335. A mechanical/chemical bond between the aluminum and uranium-aluminum fuel core is obtained by a high-pressure, elevated-temperature compacting process. The uranium content of the uranium-aluminum fuel core is 69 ± 3 wt.%. The radionuclide composition in the package loaded with four fuel elements is:

Radionuclide	wt. % of total U	max. g	max. Ci
U-234	1.2 max.	57.39	0.36
U-235	92.0-94.0	4400.0	0.01
U-236	0.7 max.	33.48	0.002
U-238	5.05-7.05	337.2	0.0001

These contents have a maximum activity of 0.372 Ci, and are equal to 3.7 A_2's to be transported. The maximum heat generation for these contents is less than 0.1 watt.

CHAPTER 2 - STRUCTURAL

2.1 Structural Design

2.1.1 Discussion

The ATR Fresh Fuel Shipping Container and the similar ETR fresh fuel container were designed and constructed in the early 1960's using only a single container (box) configuration. The outer container (box) was added in the 1968 redesign to meet certification requirements at that time. The reference SARP documents compliance of the 1968 design with 10 CFR Part 71 requirements that became effective April 1, 1996. Compliance is demonstrated by various structural analyses and engineering evaluations, supplemented by physical tests performed for the original design of the similar ETR in the late 1960's, as well as by more recent physical tests on one selected representative ATR container performed in 1992. The independent confirmatory investigations performed by the EM-76 staff, and summarized in this report, consisted of a critical review and evaluation of the material presented in Chapter 2 of the SARP submitted by the applicant, together with independent analyses to confirm the critical features of the design.

2.1.2 Design Criteria

The design criteria section of the SARP lists the mechanical and environmental loadings that govern the design of the ATR Fresh Fuel Shipping Container. The loads specified in 10 CFR 71.71 and 10 CFR 71.73 with the combinations stipulated in NRC Regulatory Guide 7.8, "Load Combinations for the Structural Analysis of Shipping Casks," are used in the structural evaluation of this packaging. The rules of the ASME B&PV Code were followed to the extent that they are applicable to the ATR Fresh Fuel Shipping Container. The primary method for demonstrating compliance with the 10 CFR Part 71 requirements for this packaging under the 10 CFR 71.73 hypothetical accident conditions is by full size prototype testing, for which qualitative rather than numerical design criteria are used.

Other structural failure modes such as brittle fracture and buckling are addressed in the SARP. Brittle fracture is not a consideration because in this packaging all the metal components are made of steel sheeting and standard 1/8-inch thickness structural shapes. These materials are not susceptible to brittle fracture.

Buckling would be possible only under the hypothetical accident conditions, and only for the following three structures: for the packaging itself, for which the steel sheeting will not buckle because it is backed up with one-inch-thick plywood panels, and this was demonstrated in the drop test of the ETR packaging; for the fuel plates themselves, for which buckling is prevented by their restraint within the fuel assembly side plates; and for the honeycomb impact limiters, for which buckling is acceptable as it is part of the expected performance of the honeycomb in absorbing the energy of an impact.

The packaging design criteria have been reviewed by the staff, and were found to be acceptable. The design criteria used in the confirmatory analysis were the same as those described above.

2.2 Weights and Centers of Gravity

The SARP lists the weight of the package with contents as 853 lb. The location of the center of gravity is given in the SARP as essentially at the geometric center. The weight of the contents is given as 88 lb. Weights of other key components are also provided.

Staff confirmatory review verified this information and found that these weights are acceptable.

2.3 Mechanical Properties of Materials

The properties listed in the SARP for the materials that affect the structural behavior of the ATR Fresh Fuel Shipping Container have been reviewed by the staff and have been found to be consistent with generally used published values. These materials include the plywood, the steel sheeting, the structural steel angles, and the aluminum honeycomb. The honeycomb is used for impact limiters that provide impact shock mitigation by crushing during a hypothetical accident drop with the packaging dropping in the end-down orientation. The seals used in the containers (boxes) do not serve a containment function, but merely protect the contents from the environment. The containers (boxes) are not part of the containment system for the ATR Fresh Fuel Shipping Container.

The hinges used to secure the cover to the container body have recently been replaced for all the ATR Fresh Fuel Shipping Containers. Since the fasteners (hinges) are considered key safety components for this packaging, all the hinges and a supply of spares were manufactured from a single controlled lot of material. The hinges on the test article that was used in the 1992 hypothetical accident drop, puncture, and thermal tests were also from this lot of material.

Staff confirmatory review has found the 1992 fastener (hinge) material, and other materials data presented in the SARP, to be adequate for the expected service and use of this packaging.

2.4 General Standards

The SARP addresses the 10 CFR 71.43 general requirements, such as minimum size and inadvertent opening. These requirements are met as follows. The smallest overall dimension is over 11 inches which is larger than the 4-inch minimum specified in 10 CFR 71.43(a). Tamper indicating security seal wires are provided on the cotter pins for the hinge pins to satisfy 10 CFR 71.43(b).

Positive closure for the ATR Fresh Fuel Shipping Container is provided by means of the hinge pins which must be removed to open that packaging. This prevents unintentional opening, as required by 10 CFR 71.43(c).

And finally, the materials used in the ATR Fresh Fuel Shipping Container are compatible with each other and no chemical or galvanic reactions would be expected between any of the materials which are in contact in this packaging.

2.5 Lifting and Tiedown Devices

The ATR Fresh Fuel Shipping Container is designed to be lifted by a fork lift. The lid lifting handles attached to the outer packaging could conceivably be used inadvertently to lift the package. The applicant presents calculations to determine the stresses in the lid lifting devices under the conditions specified in 10 CFR 71.45(a) and finds the stresses will be below yield. Using a finite element analysis, the staff has determined that there may be some local deformation of these devices, but has corroborated that the handles will not yield under a force associated with three times the weight of the packaging, which is what 10 CFR 71.45(a) requires.

The ATR Fresh Fuel Shipping Container has no tie-down devices and no structural parts that could be used for unintended tie down. Hence the requirements of 10 CFR 71.45(b) are met.

2.6 Normal Conditions of Transport

The ATR Fresh Fuel Shipping Container SARP addresses the ambient environmental conditions associated with the normal conditions of transport stipulated in 10 CFR 71.71 including hot, cold, overpressure, and underpressure, and finds that the stresses generated in the packaging are not significant, reaching at most about half of the allowable stresses. Staff confirmatory evaluation recognized that there are no loading mechanisms affecting the performance of this packaging that are generated by environmental temperature variations under normal conditions of transport. Therefore, the associated stresses are not of concern for the ATR package, as they would be for a solid steel cask that must provide a leaktight seal. The behavior of the aluminum of the fuel elements and the steel sheeting of the packaging does not transition into a brittle mode even at the -40° specified. For the ambient pressure conditions, it was recognized that the packaging provides no pressure retention and therefore the environmental pressure conditions specified in 10 CFR 71.71(c) do not affect this packaging.

The SARP addresses vibration loadings by explaining that the design does not involve features that are susceptible to vibration effects. The staff observed that the packaging uses simple positive closures that are not susceptible to vibration effects and that it contains large amounts of foam padding as well as plywood that readily damp out vibrations. The staff reviewed the information presented in the SARP, and also noted that the ATR boxes have experienced extensive usage without encountering any vibration induced problems. The staff therefore concurs that the ATR Fresh Fuel Shipping Container will perform as required under the 10 CFR 71.71(c)(5) vibration conditions. Similarly, the SARP shows that the 10 CFR 71.71(c)(6) water spray conditions will have no adverse effect on the packaging. The criticality analyses which are sensitive to water, discussed in detail in Chapter 6 - Criticality, assume the worst case water environment (optimal hydrogenous moderation) and do not rely on any water-resisting aspects of the packaging.

The ATR Fresh Fuel Shipping Container SARP addresses the effects of the normal conditions of transport four-foot drop test specified in 10 CFR 71.71(c)(7) by referring to the 30-foot hypothetical accident drop results and arguing that the 30-foot drop, being much more severe, envelopes the four-foot drop. Typically this argument is not productive because the performance requirements for normal condition tests are more demanding than those for the hypothetical accident tests. These requirements relate to containment effectiveness, radiation shielding, and criticality control. However, for the ATR Fresh Fuel Shipping Container the containment is dependent on the fuel plates and not on the packaging, and the fuel plates are not affected by the four-foot drop; radiation shielding is not a factor for this packaging; and the geometry affecting the criticality results is clearly not affected by the four-foot drop. In addition, 10 CFR 71.51(a)(1) requires that there be no substantial reduction of the effectiveness of the packaging. Based on the above arguments, the staff has concluded that all the requirements of 10 CFR 71.51(a) are satisfied for the ATR Fresh Fuel Shipping Container.

The SARP refers to both analysis and testing that shows that the 10 CFR 71.71(c)(9) compression test requirements are met. The testing was performed in 1974 by applying the specified loading for the specified period of time and observing that the packaging sustained no damage. The SARP also presents an analysis of this loading which shows that the stresses remain well below design load allowable stress levels. This affords a margin against failure that is much larger than required by the 10 CFR Part 71 rules. Either approach demonstrates that the packaging meets the 10 CFR 71.71(c)(9) requirements.

Finally, for the 10 CFR 71.71(c)(10) penetration test conditions, the ATR Fresh Fuel Shipping Container SARP contains a finite element analysis simulating this test. The analysis results are consistent with the expected damage resulting from the impact of a 13-pound steel bar dropped axially from a height of 40 inches, namely a dent in the steel sheeting covering the plywood, which is of no consequence.

2.7 Hypothetical Accident Conditions

2.7.1 Free Drop

The applicant's evaluation of the package for the hypothetical accident condition tests called out in 10 CFR 71.73 is primarily based on full-scale prototype testing, with the selection of the worst case orientation to be tested based on an evaluation of various potential drop orientations. Three orientations are relevant, as follows. The first is the drop orientation resulting in direct impact to the large flat top or bottom of the packaging.

This is the orientation resulting in the highest deceleration at impact. However, there is little damage potential in this drop since impact load is spread out and transmitted over a large area with no potential for developing large stresses or damage to the packaging. The velocity of the fuel elements is dissipated by direct bearing of the elements against the relatively soft plywood structures of the boxes. The fuel plates and the fuel elements are not expected to experience any permanent damage and the outer box will not be damaged to the extent of having openings that could affect the subsequent hypothetical accident condition thermal test results.

The end-down orientation is of concern because the fuel plates have the potential of being sheared out from the fuel element side plates. In addition, since the fuel elements are moving in their axial direction they have the potential of damaging the ends of the inner and outer boxes through their impact against the box ends. This orientation has been addressed in the ATR Fresh Fuel Shipping Container design by the addition of aluminum honeycomb shock absorbers to the packaging ends. The honeycomb limits the ATR box deceleration levels to predictable magnitudes. The characteristic property of honeycomb is that it presents a constant force over a large range of crushing distance which, for the ATR, gives a constant deceleration of about 250 g. However, the staff noted that the resistance force offered by the honeycomb at the beginning of its crushing range is considerably higher, unless the honeycomb is "precrushed" during fabrication to preclude this initial peak reaction force. Apparently this was not recognized in the design of the ATR Fresh Fuel Shipping Container nor is it addressed in the SARP. However, for the type of honeycomb used in the ATR, which is of a relatively high density, the increase in the initial force due the lack of precrush is relatively moderate; the initial force is only about twice the force present during the subsequent large deformation phase. Therefore, the staff concluded that a brief initial peak as high as 500 g is possible if the honeycomb structure is still in its initial totally undeformed state at the time of impact, and the orientation of the box at impact is such that the flat end of the impact limiter is precisely parallel to impacted surface. The SARP does demonstrate that the fuel plates will be restrained within the fuel element side plates when subjected to deceleration levels up to 1024 g and thus survive the 500 g initial loading of honeycomb. Further, adequate integrity of the packaging ends in an end drop has been demonstrated by a physical end drop of a similar packaging (the ETR packaging). Therefore the structural behavior of the ATR packaging and the behavior of the fuel plates, when subjected to an end-down orientation 30-foot drop, is acceptable.

The third orientation of concern is that which has the highest potential for producing openings in the packaging that would later be subjected to a hypothetical accident conditions thermal test. The orientation selected for this condition was the oblique orientation with impact to a long edge of the packaging, with the orientation angle selected so that the packaging center of gravity would be directly over the line of first contact at impact. This orientation was addressed by full-scale prototype 30-foot drop testing. The drop resulted in some damage to the outer box, as expected, and the test article was then subjected to a worst case puncture drop and thermal test as described below. As in the previous drop orientations, the fuel plates themselves will not be deformed by this drop orientation.

Thus the various orientations that could be relevant for a 30-foot drop are addressed, as required by 10 CFR 71.73(c)(1).

2.7.2 Puncture

For the 10 CFR 71.73(c)(2) puncture test evaluation of the ATR Fresh Fuel Shipping Container the applicant uses both testing and analysis. The worst case orientation for the puncture test itself was determined to be the drop of the packaging in a flat side down orientation with the puncture bar impact point being the center of the large flat side of the outer overpack. This orientation is not treated in the current revision of the SARP, although it was addressed by full-scale test of a packaging with effectively the same physical parameters, reported in a previous SARP, where only superficial damage consisting of about a 1/3-inch indentation of the steel sheeting over the plywood was observed. Simplified stress analysis of this test orientation, which was carried out by the staff, predicted larger deformations - on the order of about an inch. This magnitude of deformation is still quite acceptable; however, the test results should be considered the definitive results for this case.

The worst case orientation for the hypothetical accident conditions puncture test following a 30-foot drop test and preceding the thermal test was determined to be a drop of the packaging oriented with the long narrow flat side down, with the puncture bar impact point at the center of this side of the packaging. A puncture drop in this orientation would aggravate any opening or weakness that developed during the 30-foot drop. This orientation was addressed by full-scale prototype testing of the same package that was used for the prototype 30-foot oblique drop test. Both tests were performed prior to the thermal test, as stipulated by 10 CFR 71.73. Members of the staff have witnessed these tests. The staff has reviewed the test data presented, and concluded that the conditions stipulated in 10 CFR 71.73 for the structural tests were satisfied. It was noted that the puncture bar was securely mounted to the unyielding surface and remained vertical after the test. It is also noted that neither of the 40-inch drops to the puncture bar would generate any deformations of the fuel plates.

2.7.3 Thermal Stresses

The hypothetical accident conditions half-hour thermal test of the ATR Fresh Fuel Shipping Container was addressed by a physical test performed in an electrically heated oven. Differential thermal expansion due to the temperature rise of a package subjected to such a fire can be quite large and can result in high stresses in the packaging components. However, since the packaging does not provide the containment function for the ATR Fresh Fuel Shipping Container, such stresses are of no consequence here. The results of the hypothetical accident thermal test are discussed later in this report under Chapter 3 - Thermal; and the consequences of these results are discussed under Chapter 4 - Containment and Chapter 6 - Criticality.

CHAPTER 3 - THERMAL

3.1 Discussion

The analysis and test methods are used in the SARP to demonstrate that the design of the ATR package can provide adequate thermal protection to the containment boundary under the normal transport and hypothetical accident test conditions specified in 10 CFR 71.71(c) and 71.73(c)(3), respectively.

In the hypothetical accident thermal test, performed on the prototype package, the combustion and smoldering processes in the package continued for an extended period after the package was removed from the furnace. However, the post test examination of the package showed that all four dummy elements remained intact with no indication of deformation or melting, specifically in the fuel section of the element. The only region that received some deformation and cracking was the lower end box of one of the elements. Since the testing and confirmatory analyses show no melting of the fuel, the package is considered to have adequate thermal protection to meet the containment requirement specified in 10 CFR 71.51(a)(2).

The results of the staff confirmatory analyses also agree with those presented in the SARP that, for a maximum loading of four assembled ATR fuel elements, each containing a maximum of 1.1 kg (2.43 lb) of U-235 at 94 wt % enrichment, the total decay heat source in a package will be less than 0.1 watt.

3.2 Summary of Thermal Properties of Materials

The thermal properties of all package components, modeled in the analyses, have been adequately listed in the SARP and are in agreement with the values listed in the published technical reports, standards, or handbooks. The references for the data cited are also provided in the SARP.

3.3 Technical Specifications of Components

The component that requires thermal consideration is the aluminum cladding which envelops uranium-aluminum fuel core and forms the containment boundary for the contents. The cladding material is aluminum per ASTM specification B-209, alloy 6061-TO. The allowable temperature for the cladding to be 538°C (1000°F) is considered because this temperature is less than the melting temperature 585°C (1085°F) of the cladding.

The thermal and structural protection of the fuel elements is provided by the inner and outer containers fabricated from polyethylene sheet, foam rubber, plywood, and sheet steel. The technical specification of steel and plywood are discussed in Section 2.0. The foam rubber, made from RO-10-CF per specification ASTM D-1056-59T, and polyethylene sheets have the melting temperatures of 121°C (250°F) and 154°C (310°F), respectively. The allowable temperature limit of 121°C (250°F) for the package for the normal conditions of transport will assure no degradation of wood and no melting of foam rubber and polyethylene sheets. The process of slow degradation with release of combustible gases and eventual charring in wood, per Fire Protection Handbook, begins at 200°C (392°F).

For the reasons discussed in Section 3.5.1.4, the consistency in the technical specifications of the wood is not critical for the thermal performance of a package during a hypothetical accident thermal event and the conclusion of the ATR test will not change with some variations in the specifications of wood.

3.4 Thermal Evaluation for Normal Conditions of Transport

3.4.1 Thermal Model

The SARP thermal analysis for normal conditions of transport with insolation was carried out by applying the steady-state energy balance at the surface of the package. The analysis considered the insolation rates specified in 10 CFR 71.71(c) and equated the total incoming insolation heat flux on the top, side, and end surfaces of the package to the outgoing heat flux by convection and radiation to the environment. The SARP analysis is acceptable because the steady-state energy balance at the surface provides a conservative prediction when the heat source in a system is very small, such as in the ATR package where the internal heat load is less than 0.03 percent of the insolation heat flux. For additional conservatism, the analysis considered the surface absorptivity value of 1.0 and environment temperature as 54°C (130°F).

The staff confirmatory analysis also applied the steady state energy balance but only at the top surface where the insolation rate is the maximum. The analysis was performed with the environment temperature of 38°C (100°F) and the insolation rate of 800 g-cal/cm^2 for a 12-hour period, as specified in 10 CFR 71.71(b) and 71(c), respectively.

3.4.2 Maximum Temperatures

The results of the SARP and staff analyses, together with the allowable temperature limits, are presented in the following table. The package temperatures listed are the predicted peak values.

Summary of Peak Temperatures during Normal Conditions of Transport

Package	SARP °C (°F)	Staff °C (°F)	Allowable °C (°F)
In Shade	38 (100)	38 (100)	50 (122)* 82 (180)**
In Sun	102 (216)	100 (212)	121 (250)

*Non-exclusive use shipment.
**Exclusive use shipment.

For the normal conditions of transport with 38°C (100°F) ambient temperature and the package in the shade, the staff analysis confirms that the package temperature will not rise more than 0.05°C (0.1°F) above the ambient since the internal heat load from the ATR fuel is less than 0.1 watt. The packaging therefore complies with the accessible surface temperature limit of 50°C (122°F) in a non-exclusive use and 82°C (180°F) in an exclusive use shipment as specified in 10 CFR 71.43(g).

For the case of normal conditions of transport with insolation, the SARP and staff analyses calculated the maximum temperatures, at the top flat surface of the package, to be 102°C (216°F) and 100°C (212°F), respectively. These temperatures are well below the allowable temperature limit of 121°C (250°F) to assure that no degradation of wood and no melting of foam rubber and polyethylene sheets will occur during normal conditions of transport.

3.4.3 Minimum Temperatures

The staff analysis confirms that the maximum change in package temperatures due to internal heat load will be less than 0.05°C (0.1°F). Therefore, the minimum temperature of the package will be -40°C (-40°F) when exposed to an ambient temperature of -40°C (-40°F) in still air and shade, the coldest regulatory environment specified in 10 CFR 71.71(c)(2). As discussed in the structural evaluation in Section 2, the fuel plates will retain structural integrity at this low temperature.

3.4.4 Maximum Internal Pressures

The pressure will not rise in the ATR packaging since the outer and inner containers are not leaktight.

3.4.5 Maximum Thermal Stresses

The staff analysis shows that the maximum temperature gradient through the outer container wall during normal conditions of transport will be less than 0.14°C/cm (0.64°F/in). The thermal stresses resulting from this temperature gradient are discussed in the structural evaluation in Section 2.

3.4.6 Evaluation of Package Performance for Normal Conditions of Transport

The results of the SARP and staff confirmatory analyses show that the component and containment boundary temperatures of the ATR package will remain below the allowable limits. The results also show that the ATR package meets the accessible surface temperature limit requirement in a non-exclusive or an exclusive use shipment specified in 10 CFR 71.43(g).

3.5 Hypothetical Accident Thermal Evaluation

3.5.1 Thermal Model

The SARP evaluation of the ATR package under a hypothetical accident thermal event consists of analyses and a thermal test.

3.5.1.1 Analytical Model

The purpose of the analyses in the SARP was only to show that the furnace environment in the thermal test performed with the prototype package was more severe than the test conditions specified in 10 CFR 71.73(c)(3). The analyses were therefore made with a simplified one-dimensional model of the package, assuming no heat generation from wood burning, and three different environment temperature conditions. The conditions considered were: (i) The environment temperature that the package was exposed to during the 44-minute period in the furnace, (ii) the environment temperature that the package was exposed to in the furnace for the first 11 minutes, and 829°C (1525°F) for the remaining 33 minutes, and (iii) 800°C (1475°F) environment temperature for 30 minutes as specified in 10 CFR 71.73(c)(3). The analyses were performed with the SIMIR/6 computer code. The SIMIR/6, developed in 1973 for heat transfer calculations and classified as Quality Level B, is a two-dimensional code verified for operation on the IBM PS2/70 computer.

The staff has reviewed the analyses and furnace temperature measurements and agrees with the SARP conclusion that the environment conditions during the thermal test were more severe than the conditions specified in 10 CFR 71.73(c)(3).

3.5.1.2 Test Model

The thermal test was conducted on a full-scale prototype package in an electrical heating furnace. The package, following the 30-foot drop and puncture tests, was placed in the furnace preheated to 857°C (1575°F). The opening of the furnace lid and insertion of the package lowered the furnace temperature to 754°C (1390°F). A period of 13 minutes passed before the furnace temperature elevated to 843°C (1550°F) when the 31-minute thermal test began. The wood skids and bumpers on the outside started to burn soon after the package was inserted in the furnace. During the 30-minute thermal test, the combustion of wood caused the furnace temperature to reach as high as 921°C (1690°F). The combustion and smoldering of wood within the container continued for more than 18 hours after the package was removed from the furnace.

Since the package was in the heated furnace for a period of 13 minutes prior to the start of the test and the furnace temperature was maintained over 843°C (1550°F) for a period of 31 minutes, the staff agrees with the SARP that the thermal test performed on the prototype package did meet the test conditions specified in 10 CFR 71.73(c)(3).

3.5.1.3 Estimation of Peak Temperature

The thermocouples, installed in the prototype package, behaved too erratically during the test to provide any reliable data of package temperatures. To estimate the peak temperature of the fuel elements, the SARP used the knowledge that the color of the oxide layer formed on the carbon steel depends on the temperature that the steel is exposed to. The test samples, 10 cm (4 in) long and cut from the same material strips that were inserted in the dummy fuel elements in the prototype package, were separately exposed to temperatures ranging from 288 to 538°C (550 to 1000°F) for times ranging from 15 minutes to 21 hours. The colors of the test sample strips were compared with those of the strips in the fuel elements exposed to the furnace test. The comparison of colors indicated that except for the lower end box of one of the elements, the peak temperature of the fuel elements, during the furnace test, did not exceed 454°C (850°F).

3.5.1.4 Staff Evaluation

Since the combustion and smoldering phenomena in the ATR package cannot be modeled with any degree of confidence, the staff did not perform any confirmatory calculations. Instead, the staff reviewed the post-test condition of the package and the available information in the literature, to estimate the peak average fuel element temperature.

The staff estimates that the temperature of the fuel element must have reached between 321 and 500°C (609 and 932°F). The rationale for this estimate is presented below:

- \> 154°C (310°F):

  The foam pads and polyethylene sheets, surrounding the fuel elements, were completely melted and the melting temperatures of foam and polyethylene are 121°C (250°F) and 154°C (310°F), respectively.

- \> 320°C (608°F):

  The trapezoidal wood pieces between the fuel elements in the inner container were found cracked and charred. The cracking in the wood burning process, as discussed by A. F. Roberts in his paper in the 13th Symposium (International) on Combustion, Combustion Institute (1971), begins mainly in the temperature range of 300 to 320°C (572 to 608°F). The cracking observed in the trapezoidal pieces implies that the temperature near fuel elements must have been greater than 320°C (608°F).

- \> 321°C (609°F):

  Most of the cadmium in the lid of the inner box melted and the melting temperature of cadmium is 321°C (609°F). The temperature in the outer surface region of the inner box must have reached above 321°C (609°F).

- < 585°C (1085°F):

  The dummy elements were found to be intact with no indication of any deformation or melting, specifically in the fuel section of the element and the melting temperature of aluminum cladding is 585°C (1085°F). The only region that received any deformation and cracking, which was very minor, was the lower end box of one of the elements.

- < 500°C (932°F):

  In the wood burning process, described in Chapter 3 of Fire Protection Handbook by A. E. Cote, Seventeenth Edition (1991), an exothermic reaction, producing flammable vapors and particulates, occurs in the temperature range 280 to 500°C (536 to 932°F) and for the temperature over 500°C (932°F), the residue is principally charcoal and/or ash. The trapezoidal wood pieces in the inner container, after the thermal test, were found only cracked and charred without turning into charcoal or ash.

The staff review of the following information in the literature suggests that the conclusion of the ATR test will not change with some variations in the specifications of wood.

- The heat of combustion per unit of oxygen consumed is nearly constant for most organic fuels. (Reference: last paragraph in page 15-4 of Wood Handbook: Wood as an Engineering Material, prepared by Forest Products Laboratory, U.S. Department of Agriculture, 1987, and fourth paragraph, page 3-23 of Fire Protection Handbook by A. E. Cote, Seventeenth Edition).

- The technical specification of wood is important mainly for structural consideration and not for combustion because the major difference between various woods depends largely on density (specific gravity), which is related to cell wall thickness or strength properties. (Reference: third paragraph in Section "Chemical Composition of Wood," page 3-23 of Fire Protection Handbook by A. E. Cote, Seventeenth Edition).

- Table 3-3A, page 3-23 of Fire Protection Handbook by A. E. Cote, Seventeenth Edition shows that the chemical composition is nearly the same for all types of wood.

3.5.2 Package Conditions and Environment

The test results presented in the SARP, and verified by staff observation of the drop test results, show that the damage from the drop and puncture events will be some deformations of the outer box and the outer box hinges that will cause about 3 mm (0.125 in) wide opening between the lid and base of the outer container. The drop and puncture tests will not cause any fracture of the outer container sheet metal or the hinges or any damage to the fuel elements or the inner container. The post thermal test examination of the package showed that much of the wood and trapezoidal pieces in the inner container were only charred, smoldered, and cracked without turning into charcoal or ash. The results confirm that the inner box had not deformed from the drop and puncture test to allow excess air to flow in.

3.5.3 Package Temperatures

From the containment consideration, the temperature of the fuel element is the only information needed to assess if the package meets the regulatory requirements during a hypothetical accident thermal event. Because the wood burning process cannot be modeled with any degree of confidence and the thermocouples, installed in the prototype package, provided no reliable data, only the upper bounding temperature of the fuel elements can be estimated. The SARP used the color of the oxide layer of the carbon steel strips and the staff used the post-test condition of the package to estimate the upper bounding temperatures of the fuel elements. The SARP and staff estimations, together with the allowable temperature limits, are presented in the following table.

Summary of Peak Fuel Element Temperatures during Hypothetical Accident Thermal Event

Component	SARP °C (°F)	Staff °C (°F)	Allowable °C (°F)
Fuel Element	<454 (850)	<500 (932)	538 (1000)

The staff and SARP estimations of the upper bounding temperatures show that during the hypothetical accident thermal test, the fuel element temperatures remained below the allowable limits.

Even though the margin of 38°C (68°F), between the allowable limit and the staff estimated upper bounding temperature, appears to be small, the following reasons provide further assurance that the package has adequate thermal protection to meet the containment requirements specified in 10 CFR 71.51(a)(2).

- The thermal test, discussed in Section 3.5.1.2, was more severe than the test conditions specified in 10 CFR 71.73(c)(3).

- The staff estimate of 500°C (932°F), listed in the above table, is conservative because this temperature is the upper bounding value in the staff estimated range of 321 to 500°C (609 to 932°F). Furthermore, the peak average fuel element temperature in the thermal test must have been less than 500°C (932°F) because for temperatures over 500°C (932°F), wood residue is principally charcoal and/or ash, while all of the trapezoidal wood pieces near the fuel elements were only cracked and charred, but not turned into charcoal and/or ash.

- An added safety margin exists because the melting temperature of the cladding is 47°C (85°F) above the allowable limit of 538°C (1000°F).

- The post thermal test examination showed no sign of any melting in the fuel section of the fuel elements.

3.5.4 Maximum Internal Pressures

The package has no seals to cause any pressure buildup. Furthermore, in the prototype testing, the deformation from the drop and puncture tests added a large enough opening, about 3 mm (0.125 in) wide between the lid and base, to allow venting of combustion products during the thermal test. The post test examination after the sequence of hypothetical accident tests on the prototype package showed that the outer and inner containers had retained their structural integrity.

3.5.5 Maximum Thermal Stresses

The post-test examination after the thermal test on the prototype package showed no deformation of the inner container and only a small outward bulge in the outer container. The structural integrity of the package after the sequence of hypothetical accident tests is discussed in the structural review in Chapter 2 - Structural.

3.5.6 Evaluation of Package Performance for Hypothetical Accident Thermal Conditions

The SARP has demonstrated and the staff review has confirmed that the ATR packaging can provide adequate thermal protection during the hypothetical accident thermal event to maintain the containment boundary below the maximum allowable temperature limit.

3.6 Conclusion

The staff concludes that the ATR Package thermal features have been designed adequately and will provide reasonable assurance that the regulatory requirements of 10 CFR Part 71 and 49 CFR Part 173 have been met.

CHAPTER 4 - CONTAINMENT

The ATR Fresh Fuel Shipping container is designed to ship up to four uranium fuel elements with a maximum enrichment of 94 wt.%. The radioactive contents of the ATR Fresh Fuel Shipping Containers are limited to four unirradiated ATR fuel elements containing no more than 0.431 Ci of enriched uranium based on a maximum loading of 1100 g of U-235 per element. These quantities amount to less than 4.31 A_2. The preceding calculations were based on a worst case loading of fuel with maximum enrichment of 95 wt.%. Therefore, with respect to containment issues, four uranium fuel elements with a maximum enrichment of 95 wt.% can be shipped.

The containment boundary for the ATR Fresh Fuel Shipping container consists of the fuel plate cladding and the uranium-aluminum alloy matrix fuel. The containment boundary was evaluated using "Specification For Advanced Test Reactor Mark VII Zone Loaded Fuel Elements," March 18, 1993, IN-F-9-ATR, Rev.14; "Specification For Advanced Test Reactor Mark VII Zone Loaded Non-Borated Fuel Elements," March 18, 1993, IN-F-10-ATR, Rev. 2; "Specification For Advanced Test Reactor Special Non-Fueled Plate 19 7F Fuel Elements," May 28, 1992, IN-F-9A-ATR, Rev. 3; "Specification for Aluminum Powder Matrix Material in Test Reactor Fuel," September 8, 1987, IN-F-4-TRA, Rev. 9; "Specification for Reactor Grade High Enriched Uranium Aluminide (UAl_x) Powder," May 28, 1992, IN-F-5-TRA, Rev. 9; "Specification for Boron Carbide Powder in Test Reactor Fuel," September 8, 1987, IN-F-6-TRA, Rev. 7; and "Specification for High Enriched U-Metal for UAl_x Reactor Fuel Elements," September 8, 1987, IN-F-7-TRA, Rev. 6; provided in the Appendices of Chapter 4 - Containment of the SARP and the fuel plate drawings listed in Section 1. The staff confirmatory analyses focused on whether the cladding will remain leaktight and the surface contamination will not be increased during all conditions of transport.

4.1 Normal Conditions of Transport

4.1.1 Leaktightness

The confirmatory analysis for cladding leaktightness considered the following three possible threats to fuel containment during transport:

1. Mechanical deformation
2. High temperature
3. Corrosion

4.1.1.1 Mechanical Deformation

The fuel core for the plates is fabricated by powder metallurgy methods. Uranium aluminide fuel fines with a uranium content of 69 wt.% ±3.0 wt.% ranging in size from 100 to 325 mesh (44 μm to 150 μm) are homogeneously blended with aluminum alloy fines encapsulated and evenly interspersed throughout the core. The fuel core for the plates is clad with 6061-TO Al alloy. The fuel cladding for Plates 2-18 is nominally 0.015 in. thick, and Plates 1 and 19 have a nominal thickness of 0.030 and 0.040 in. respectively. The minimum cladding thickness is 0.008 in. for Plates 2-18, and 0.018 in. for Plates 1 and 19. These required thickness values are verified by ultrasonic inspection. A metallurgical bond between the fuel core and the cladding is formed by hot rolling at a temperature of 850°F ±30°F during the fabrication process. Annealed 6061-TO aluminum alloy cladding has a 25% elongation capacity at room temperature. The ductility of the core inside the cladding decreases with decreasing volume fraction of aluminum in the core. If a fuel plate is bent, a crack in the relatively thick fuel core can concentrate stretching of the thin clad at that point and cause rupture. The SARP addresses the ductility of the fuel matrix by reference to the 2t bend radius test, 20% surface strain in Appendix 4C of the SARP. Also the staff is aware of testing in which an MTR-type fuel plate, fabricated as the ATR fuel plates, was bent up to 80° around a small radius as stated in ANL/RERTR/TM-10 and the bending did not breach the cladding even though the deformation was greater than can occur even under Hypothetical Accident Conditions.

Initial cladding integrity is verified by ultrasonic inspection and a blister test (nonbond indication) at 900°F for two hours for every fuel plate. Acceptable bonding, defined as no visible separation between the layers when viewed at 50X magnification and with grain growth evenly distributed across a minimum of 50% of the aluminum-to-aluminum portion of the interface length, was verified by destructively testing one plate of a qualification batch of twenty fuel plates of each of the nineteen fuel plate sizes. Each plate was completely sectioned transversely at four locations covering the length, and two locations longitudinally at both ends of the plate. The ultrasonic inspection, the blister test, and the preceding destructive test ensure that each fuel plate is properly fabricated, and thus is able to pass the extreme 80° bending test without the aluminum fusion bonds breaking and releasing contamination. Operational experience was cited in the SARP in which there were fuel shipments over a 23-year period with no release of radioactive material. With a measurement sensitivity of 1000 dpm or less and a routine transfer/shipment time of 20 hours, the leak rate was found to be 0.99×10^{-7} A_2 per hour or less. Therefore, the ATR Fresh Fuel container containment, which is the fuel plate cladding, satisfies the regulatory requirement for a release of less than an $A_2 \times 10^{-6}$ per hour specified in 10 CFR 71.51(a)(1) for the Normal Transport Conditions.

4.1.1.2 High Temperature

Irradiated MTR-type fuel plates have been heated to a temperature of 1085°F, as cited in the SARP, without release of fission gases indicating that the fusion bond between the aluminum cladding and the Al-U fuel core remains intact at high temperatures. Unirradiated fuel has not been degraded by reactor operation, and therefore, the spent fuel results are a worst case with respect to the containment of ATR unirradiated fuel. The safety margin is larger still because the 216°F maximum fuel temperature cited in the SARP for ATR unirradiated fuel elements during normal conditions of transport is much less than the 1085°F temperature of the tests. Therefore, containment will not be compromised during normal conditions of transport due to increased temperature.

4.1.1.3 Corrosion

Aluminum is a highly electropositive element and would react rapidly with oxygen or water except for a very thin but highly protective oxide film that instantly forms on any exposed fresh surface. At room temperature, this film is penetrated and the aluminum is rapidly attacked by strong alkaline solutions. Protection from such attack is provided by the shipping container which keeps accidental liquid splashes from reaching the aluminum. Therefore, corrosion prevention meets the intent of 10 CFR §71.43(d).

4.1.2 Contamination

Contamination remaining on the outer surfaces of the cladding after fabrication is less than 1.632 μCi for four ATR fuel elements. These quantities correspond to 1.632 x 10^{-5} of an A_2 value for four ATR fuel elements. The confirmatory analysis showed that if the non-fixed external contamination remaining on the fuel plates after post-fabrication cleaning were smeared over the external surface of the package, the contamination would be as much as 4.66 x 10^{-5} μCi/cm^2. This is above the limit of 1.0 x 10^{-5} μCi/cm^2 specified in 10 CFR 71.87(i) for any time during transport but below the limit of 1.0 x 10^{-4} μCi/cm^2 specified in 10 CFR 71.87(i) for exclusive use shipments by rail or highway only. Therefore, the Certificate of Compliance is conditioned on shipping the ATR packaging as exclusive use.

4.2 Hypothetical Accident Conditions

The evidence that the ATR fuel plate cladding containment will remain leaktight during normal conditions of transport is, in general, also sufficient to show leaktightness during hypothetical accident conditions. Staff analyses described in Chapter 2 - Structural above show that the packaging suffers only minor damage during the hypothetical accident conditions and thus protects the ATR fuel elements from mechanical damage. Under accident conditions, melting of the aluminum clad would begin at the 1080°F solidus temperature of 6061 alloy. Staff analyses described in Chapter 3 - Thermal show ATR fuel clad temperatures of less than 932°F and thus no melting of the aluminum cladding containment boundary nor release of contents is possible under Hypothetical Accident Conditions. Therefore, the regulatory requirement, stated in 10 CFR 71.51(2), of a radioactive release of less than an A_2 value in a week is satisfied.

The evaluation of the containment design by the staff provides reasonable assurance that, from the standpoint of general requirements on the packaging and under both Normal Transport Conditions and Hypothetical Accident Conditions, radioactive material can safely be transported in the ATR Fresh Fuel Shipping container.

The staff concludes that the containment boundary of the ATR Fresh Fuel Shipping container will not release radioactive material in excess of the regulatory limits allowed by NRC regulations and DOE Orders under both normal conditions of transport and hypothetical accident conditions and will provide reasonable assurance that the regulatory requirements of 10 CFR Part 71, 49 CFR Part 173, and DOE Order 460.1A have been met.

CHAPTER 5 - SHIELDING

The ATR Fresh Fuel Shipping Container is used for shipping up to four unirradiated ATR fuel elements. Each ATR fuel element contains less than 1,196 g of all uranium isotopes and less than 1,100 g of U-235 with a maximum enrichment of 94%. Four fuel elements are placed in an inner container, which is in turn placed in an outer container. Unirradiated U-235 emits radiation such as alphas, electrons, and photons, but the radiation is readily shielded by the aluminum alloy cladding. The SARP cites a radiation survey of individual fuel elements and the container; the results showed beta/gamma readings of 9-10 mR/h at the surface of individual fuel elements, and 1.4-1.5 mR/h on the top surface of the ATR container. These readings are well below the 10 CFR Part 71 dose rate limits for normal transport (200 mR/h at the container surface and 10 mR/h at 2 m away from the container surface) and Hypothetical Accident Conditions (1,000 mR/h at 1 m from the container surface).

Neither the SARP nor this SER specifies the Transport Index (TI) for radiation because the TI for criticality control is the larger (controlling) value. The TI for radiation is defined as 100 times the radiation dose rate in mR/hr at 1 m from the surface of the container and is much smaller than the TI for criticality control described in Chapter 6.

Based on the evidence obtained in the radiation survey of the unirradiated ATR fuel elements and container, the staff agrees with the conclusion in Chapter 5 of the SARP that the ATR Fresh Fuel Shipping Container complies with the radiation shielding requirements specified in 10 CFR Part 71 for normal transport and hypothetical accident conditions.

CHAPTER 6 - CRITICALITY

6.1 Normal Conditions of Transport

The staff performed confirmatory criticality analysis using models for the ATR fuel elements and shipping containers that are identical to those depicted in Figs. 6-3 and 6-4, Chapter 6 of the SARP with one exception. The fuel elements in these figures contain 1100 g with an enrichment up to 93 wt.% U-235. At the applicant's request to cover ATR fuel elements with U-235 enrichment slightly higher than 93 wt.% but within manufacturing tolerances, the staff's confirmatory criticality analysis is for enrichments up to 94 wt.% U-235. The confirmatory calculations have been performed using KENO V.a with the 27 energy group ENDF/B-IV cross section library. The computer platform for KENO V.a, a module in the SCALE 4.2 code system, is an IBM RISC/6000 Model 390 workstation at Argonne National Laboratory. For conservatism, the confirmatory analysis assumes that the polyethylene bag around the fuel element, which is a poorer moderator than water, is absent and the gaps between the fuel plates in each of the four fuel elements and the inner and outer containers are flooded with water, either in a configuration of a single undamaged package or an infinite array of undamaged packages. The latter infinite array of packages represents a more reactive configuration than the 60 packages that are required by regulation (10 CFR 71.59) in the criticality evaluation for fissile material shipment.

The calculated neutron multiplication factors (k_{eff}) for 94 wt.% U-235 enriched ATR fuel elements are 0.419±0.003 and 0.447±0.003, respectively, for a single undamaged package flooded with water and for an infinite array of undamaged packages flooded with water. The corresponding values of k_{eff} listed in the

SARP are 0.414±0.002 and 0.445±0.002, respectively. All of these values are far below the criticality criterion of k_{eff} = 0.95. Subcriticality, therefore, is assured for the ATR fresh fuel shipping container under normal conditions of transport.

6.2 Hypothetical Accident Conditions

In the confirmatory analysis, the staff modeled the hypothetical accident conditions based on the results of an actual ATR shipping container following a fire test. Because the wood in the outer container burned in the fire test, the inner container was assumed to be able to move anywhere on the bottom steel surface of the outer container. Cadmium and polyethylene sheets in the inner container were excluded from the model, as both materials melted in the fire test. Even though the trapezoidal wooden spacers between the fuel elements were only charred in the inner container, a much smaller spacing, on the order of the 2 mm spacing between the fuel plates within a fuel element, was assumed for the fuel elements, thus bringing them much closer than the spacing (27.4 mm) observed in the fire-damaged ATR shipping container.

In addition to the above conservative assumption on the spacing between fuel elements in the inner container, the 24 ATR shipping containers (obtained as two times the number of damaged containers and each consisting of an inner and an outer container) that are required by regulation (10 CFR 71.59) for criticality evaluation are assumed to be stacked in the most reactive configuration in the KENO V.a calculations. This configuration, designated as 2x1x12, and the fuel element layout in each shipping container are also identical to those depicted in Figures 6.5 and 6.6, Chapter 6 of the SARP. Any other configuration, such as 3x1x8, 4x1x6, or 2x2x6, etc., would result in a less dense packing of the ATR fuel elements than the 2x1x12 arrangement, hence generally lower calculated values of k_{eff}, as indicated in Table 6-4, Chapter 6 of the SARP.

The table below shows the calculated k_{eff} values for the most reactive stacking configuration (2x1x12) over a range of volume fractions, VF = 0.14 to 0.25, of water assumed present in the shipping containers. The staff's confirmatory analysis shows that the k_{eff} value decreases at water volume fractions below 0.150, the minimum water volume fraction investigated in the SARP.

The last column in the table gives adjusted values of k_{eff} that include a negative bias of 1.2% (determined from the criticality benchmark experiments) and the product of two times the KENO V.a-calculated standard deviations. The highest value of k_{eff} obtained in this manner is 0.948, which is still lower than the criticality criterion of k_{eff} = 0.95. Given the ultra conservative assumptions made in the models for fuel element spacing and container stacking, and given the fact there are only 21 ATR containers authorized by the Certificate of Compliance (Serial Numbers 4 through 24), the staff concludes that subcriticality is assured for the ATR Fresh Fuel Shipping Container under hypothetical accident conditions.

VF	k_{eff} (SARP Table 6.4)	k_{eff} (Staff)	Adj. k_{eff} (Staff)
0.140		0.92672±0.00138	0.94060
0.145		0.93269±0.00147	0.94682
0.150	0.931±0.002	0.93392±0.00147	0.94807
0.200	0.933±0.001	0.92941±0.00144	0.94344
0.250	0.924±0.002	0.92428±0.00145	0.93287

In summary, the staff confirms the SARP finding that the ATR Fresh Fuel Shipping Container complies with the criticality safety requirements specified in 10 CFR Part 71 for normal transport and hypothetical accident conditions.

For the ATR container, the TI for criticality control is 4.1, a much larger value than the TI for radiation control. This value of TI limits the number of ATR containers that may be shipped in a single exclusive use shipment to 24; however, there only 21 ATR containers, serial numbers 4 through 24 authorized by the Certificate of Compliance.

CHAPTER 7 - OPERATING PROCEDURES

The operating procedure requirements presented in Chapter 7 of the SARP provide specific guidance for:

1) loading, closure, and preshipment checks,
2) receiving checkout, opening, and unloading, and
3) empty packaging preparations.

Each container must first be inspected and discrepancies corrected before being approved for use. The inspection and repair criteria are put forth in Section 8.2 of the SARP.

Radiation surveys are prescribed to ensure an acceptable radiation source for the contents to protect loading and handling personnel and to ensure compliance with shipping regulations.

The staff finds that the operating procedure requirements presented in the SARP are acceptable and will provide reasonable assurance that the regulatory requirements of 10 CFR Part 71, 49 CFR Part 173, and DOE Order 460.1A have been met.

CHAPTER 8 - ACCEPTANCE TESTS AND MAINTENANCE PROGRAM

The Acceptance Tests discussed in Section 8.1 of the SARP are applicable to the fuel plates, of which the uranium-aluminum alloy matrix and aluminum cladding provide containment. The containment boundary is integral to each fuel element plate. The fabrication inspection requirements for the fuel plates and element assemblies are defined in "Specification For Advanced Test Reactor Mark VII Zone Loaded Fuel Elements," March 18, 1993, IN-F-9-ATR, Rev. 14; "Specification For Advanced Test Reactor Mark VII Zone Loaded Non-Borated Fuel Elements," March 18, 1993, IN-F-10-ATR, Rev. 2; and "Specification For Advanced Test Reactor Special Non-Fueled Plate 19 7F Fuel Elements," May 28, 1992, IN-F-9-ATR, Rev. 3; provided as Appendices to SARP Chapter 4.

Acceptance Tests and Procurement Requirements are not provided in the SARP for the inner and outer boxes of the ATR Fresh Fuel Shipping Container. No new containers have been fabricated since the 1960s and the Acceptance Tests and Procurement Requirements are not available for the inner and outer boxes. The SARP demonstrates that the existing containers have acceptable quality and consistency of their critical components by examination, reasoned argument, replacement of some critical components with pedigreed components, and Hypothetical Accident Condition testing of one of the existing containers. The components replaced were the hinge and pin assemblies of both the inner and outer boxes of the package. Extra hinge and pin assemblies were purchased to accommodate future repairs of the existing containers.

No new packages shall be procured until this SARP is revised to include acceptance tests and procurement criteria requirements for the inner and outer boxes of the ATR Fresh Fuel Shipping Container.

Section 8.2 of the SARP discussed the Maintenance Program which focused on the inner and outer boxes of the shipping containers. Specific features to be inspected prior to shipment use are tabulated in Table 8.1 of the SARP. Again, it is noted that the containment boundary is integral to each individual fuel plate in the fuel assembly, and since the shipment of an unirradiated fuel assembly is a one-way, one-time shipment, no maintenance plan is required for the containment boundary.

The staff finds that the acceptance tests for the fuel elements and maintenance program requirements for the inner and outer boxes presented in the SARP are acceptable for existing ATR Fresh Fuel Shipping Containers serial numbers 4 through 24 and will provide reasonable assurance that the regulatory requirements of 10 CFR Part 71, 49 CFR Part 173, and DOE Order 460.1A have been met for the existing containers.

CHAPTER 9 - QUALITY ASSURANCE

The requirements for a Quality Assurance (QA) Plan presented in the QA Chapter 9 of the SARP have been reviewed and found to meet the QA requirements of 10 CFR Part 71, Subpart H. These QA requirements provide sufficient control over all items and quality-affecting activities that are important-to-safety as applied to the design modification of existing containers and of ATR fresh fuel elements; procurement and fabrication of replacement parts; and testing, operation, maintenance, and repair of the ATR Fresh Fuel Shipping Container. The QA requirements are based on a graded approach as described in

10 CFR 71.101. The graded approach in the QA Chapter includes an important-to-safety Q-list for each item and quality-affecting activity and is graded based on the design function of the item relative to the safety and performance requirements for the complete shipping package. The Q-list uses three QA levels with associated definitions for each. The QA level of each important-to-safety item is based on the specific criteria, and the necessary level of QA requirements is invoked for each item. The QA requirements assure that the ATR Fresh Fuel Shipping Container is designed, fabricated, and tested in accordance with the drawings identified in the SARP. In addition, the QA Chapter requires the user to invoke the same level of QA requirements for the use, maintenance, and repair of the packaging as is required for the procurement, fabrication, and acceptance testing of the original packaging. The QA levels for important-to-safety items and activities are based on the following definitions:

1. Category A (Critical)

   Category A - Level 1 applies to items, e.g., ATR fuel plates, critical to safe operation. These could be structures, components, systems, or products whose failure or malfunction could directly result in a condition adversely affecting public health and safety as a result of a single event failure. This would include loss of primary containment with subsequent release of radioactive material, loss of shielding, or an unsafe geometry comprising criticality control.

2. Category B (Major)

   Category B - Level 2 applies to items with a major impact (which is less than critical impact) on safety. These items could be structures, components, or systems whose failure or malfunction could indirectly result in a condition adversely affecting public health and safety. An unsafe condition could result only if the primary event occurs in conjunction with a secondary event or other failure or environmental occurrence (dual event failure criteria). An example is the hinge-pin assembly.

3. Category C (Minor)

   Category C - Level 3 applies to items with a minor impact on safety. These items could be structures, components, and systems whose failure or malfunction would not significantly reduce the package effectiveness and would unlikely create a condition adversely affecting public health and safety (multiple event failure criteria).

After determining the applicable QA level, the appropriate level of QA effort for design, procurement, fabrication, testing, operations, maintenance, modification, and repair activities is determined from the 18 QA elements identified in 10 CFR Part 71, Subpart H and ASME-NQA-1. The 18 elements identified in the SARP are organization; quality assurance program; design control; procurement document control; instructions, procedures, and drawings; document control; control of purchased material, equipment, and services; identification and control of material, parts, and components; control of special processes; inspection control; test control; control of measuring and test equipment; handling, shipping, and storage control; inspection, test, and operating status; control of nonconforming materials, parts, or components; corrective action; QA records; and QA audits.

The QA Chapter of the SARP includes independent verification of operational activities considered to be critical in satisfying the regulatory requirements for containment, shielding, and subcriticality as identified in 10 CFR Part 71. Verification of critical operating and inspection points is contained in the ATR fuel specifications for fuel elements and Sections 7.1.3, 7.2.3, 7.3.2, and 8.2.1. of the SARP. The SARP specifies that no additional ATR Fresh Fuel Shipping Containers shall be procured to the current design, procurement, and fabrication requirements.

The staff concludes that the QA requirements presented in the SARP are in conformance with the established criteria in Subpart H of 10 CFR Part 71 and will assure that any design modification of existing ATR Fresh Fuel Shipping Containers and of ATR fresh fuel elements; procurement and fabrication of replacement parts; and testing, inspection, operations, maintenance, or repair of the ATR Fresh Fuel Shipping Container will be accomplished in accordance with the requirements presented in the SARP and will provide reasonable assurance that the regulatory requirements of 10 CFR Part 71, 49 CFR Part 173, and DOE Order 460.1A have been met.

Michael E. Wangler

Michael E. Wangler
Headquarters Certifying Official
Office of Transportation, Emergency
Management and Analytical Services, EM-76

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